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Radiation dose in CT colonography–trends in time and differences between daily practice and screening protocols

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Abstract The purpose of this study was to evaluate the currently used effective doses in CT colonography (CTC) and to search for trends in time. A Pubmed search for articles and a search for congress abstracts concerning CTC was performed. Research institutions were sent a CTC dose questionnaire concerning the type of CT system employed and the CT parameters used. With the ImPACT CT Dosimetry Spreadsheet effective doses were calculated. Of 83 institutions, 34 returned a complete questionnaire; 21 (62%) used 64-detector row CT and 17 (50%) used dose modulation. The median effective dose per institution was 5.7 mSv (2.8 mSv supine; 2.5 mSv prone) for screening protocols and 9.1 mSv (5.2 and 3.0 mSv, respectively) for daily practice protocols ($p<0.05$). Doses did not differ significantly between CT machines with different numbers of detector rows. In 17 institutions incorporated in a study in 2004 as well, the median dose for daily practice protocols changed from 11 mSv in 2004 to 9.7 mSv now (n.s.). Median effective dose for CTC is significantly lower for screening than for daily practice protocols. Although the number of CTC protocols with dose modulation increased substantially since 2004, no significant decrease in effective dose was found.

Keywords CT colonography · Radiation dose · Colorectal neoplasms · Computed tomography

Introduction

Currently, multi-detector computed tomography (CT) systems with a large number of detector rows (e.g., 40 or 64), dose modulation or automated current selection (ACS) is widely used for all applications including CT colonography (CTC). These technical improvements will have an effect on image quality, but also on radiation exposure. Dose efficiency is improved with an increasing number of detector rows due to the decrease of the effect of overbeaming, which is the additional radiation due to the penumbra effect [1]. On the other hand, dose efficiency is lost with machines with a larger number of detector rows, because of increased amount of overranging, which is the difference between the exposed length and the planned length of the CT examination [2, 3]. ACS automatically adjusts the tube current to the size of the patient to reduce the differences in noise level between thin and thicker patients. Differences in image quality will therefore be reduced for patients of different sizes [4]. Dose modulation adjusts the tube current according to the changing patient anatomy. This can give an overall reduction in dose level per patient, while the image quality is preserved [5, 6].

For CTC it is important to reduce radiation dose for optimization of the benefit-risk ratio of the examination, especially when used in low-risk screening patients. The life-time cancer risk associated with the radiation exposure using a typical current CT technique for paired (supine and prone) CTC was estimated to be 0.14% for a 50 year old, which might be reduced by factors of 5 or even 10 with optimized CTC protocols [7]. Important is however to identify acceptable thresholds of image quality so that radiation dose optimization can take place [4]. In earlier research it was found that with low doses still good image

quality and high diagnostic accuracy were obtained at CTC [8–11].

In a previous study the effective radiation dose in CTC protocols of 28 research institutions was surveyed [12]. Most institutions at that time used CT systems with 4, 8 or 16 detector arrays. The median effective dose per institution was 5.1 mSv per position and 10.2 mSv in total. No CT systems with more than 16 detector rows, no dose modulation or automated current selection were used at that time. The aim of the present study was to investigate the current effective dose for CTC in daily practice and screening protocols and to compare doses for the protocols used with machines using different numbers of detector rows. Furthermore, current effective doses were compared with the results of the former dose evaluation study.

Methods

Dose questionnaire

A Pubmed search was performed with MESH heading 'CT colonography,' and all articles published from January 2004 until January 2007 describing a study on CTC accuracy were selected. Articles in a language other than English or case reports were excluded. Furthermore, all abstracts of the Congress of the Radiological Society of North America (RSNA) 2006, European Congress of Radiology (ECR) 2006 and the Symposium on Virtual Colonoscopy in Boston 2006 were searched for studies with CTC. In addition all institutions that were invited for a questionnaire in the study by Jensch et al. [12] were included, if this was not yet the case. All selected institutions received a mail in which they were invited to fill in a questionnaire. Reminder e-mails were sent after 4 and 7 weeks. In Table 1 the questions of the dose evaluation questionnaire are listed. The data for the present study were collected between April and September 2007.

Table 1 Questions in the dose evaluation questionnaire

Daily practice protocol?	y/n
Type of patients for DP protocol:	-Symptomatic
	-Surveillance
	-Other:
Screening protocol?	y/n
Type of CT scanner:	(Manufacturer and type)
Number of slices:	1, 2, 4, 8, 16, 40 or 64
Collimation per slice:	...mm
Tube voltage:	...kV
Rotation time:	...s
Pitch (table feed per rotation/ total collimation):	...
For scans without automatic current selection or dose modulation:	
-Tube current: or	...mA
-Tube current × rotation time: or	...mAs
-Tube current × rotation time/ Pitch:	...effective mAs or mAs per slice
For scans with automatic current selection and/or dose modulation (for an average male patient, i.e., approximately 170 cm and 70 kg):	
-Length patient:	...cm
-Weight patient:	...kg
-Preset or reference mAs (if available)	...mAs
-Realized DLP: and/or	...mGy*cm
-Realized average mAs: and/or	...mAs
-Realized CTDI vol:	...mGy
-Length of scan or scans:	...cm
-Use of X/Y modulation:	y/n
-Use of Z modulation:	y/n

Institutions were asked to complete the form for both supine and prone protocols and for the daily practice and screening protocols (or only one protocol if not both in use). Indications for daily practice patients were: (1) symptomatic patients with symptoms of colorectal cancer or other colorectal disease, (2) surveillance patients for repeat examination on colorectal cancer or other colorectal disease or (3) DLP: dose length product. CTDIvol: computed tomography dose index

Estimation of effective doses

The effective dose for each protocol was estimated using the ImPACT CT Dosimetry Spreadsheet (www.impactscan.org/ctdosimetry.htm) [13, 14]. With this spreadsheet effective doses can be calculated for a hermaphrodite with a length of 170 cm and a weight of 70 kg [15]. In the calculation of effective dose, a nominal scan trajectory of 43 cm was assumed (from the diaphragm to the groin). Data for the additional anatomical length exposed due to overranging were obtained from the CT-Expo spreadsheet, and the effective length of the volume examined was used in the calculation of the effective dose [16].

Calculation of effective dose is straightforward for the situation without ACS or dose modulation. With ACS the tube current is constant, but depends on the size of the patient, and with dose modulation the tube current also varies per slice and per tube angle (in case X/Y modulation is used), which complicates the calculations of effective dose. In this situation we used the *average* effective mAs value that was used for a CTC of an average-sized patient of 170 cm and 70 kg. In case not the effective mAs, but the CTDIvol was provided, the average effective mAs was obtained from the ImPACT spreadsheet; when the dose-length product (DLP) was provided the CTDIvol was obtained by dividing by the length of the volume examined. In case data for patients of deviant weight were provided, the effective mAs value for a patient of 70 kg was

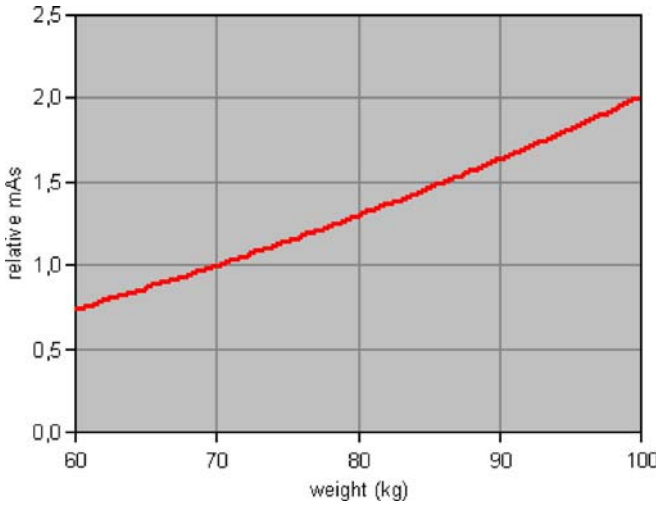

Fig. 1 Example of relation of tube current and weight in CT systems when dose modulation is applied

Table 2 Corrections of mAs values according to weight in 6 institutions

	Position[a]	Weight (kg)	mAs	mAs[b]
Daily practice				
Berlin	Supine/prone	75	56	49
Leuven	Prone	80	15	12
London	Supine/prone	67	113/110	123/120
Perth	Supine	75	200	175
Ulm	Supine/prone	84	162	113
Screening				
Buenos Aires	Supine/prone	80	49	38
Leuven	Supine	79	51	40
	Prone	80	16	12
Ulm	Supine/prone	76	49	42

[a]Position: patient position where dose modulation is applied. [b]mAs: corrected mAs value for weight

estimated with an empirical relationship, using data of Kalra et al. [17] (see Fig. 1).

Data of the CTC protocols for daily practice and screening were evaluated separately, and classified according to the number of detector rows of the CT machine in question. When an institution used protocols with and without dose modulation, the protocols with dose modulation were used. However, when an institution used more than one protocol for daily practice or screening that differed otherwise, both protocols were used, and the average effective dose for the institution was calculated. Results of dose calculations were sent to all institutions to check for possible errors.

Of the institutions that returned a questionnaire in a former CTC dose evaluation study as well [12], comparisons were made between the effective dose at that time (2004) and now. At that time overranging was not taken into account and therefore we recalculated the effective doses for this study including the effect of overranging. The number and percentages of multi-detector row CT systems with a different number of detector rows were calculated for 2004 and 2007, as were the number of institutions that used dose modulation in 2007.

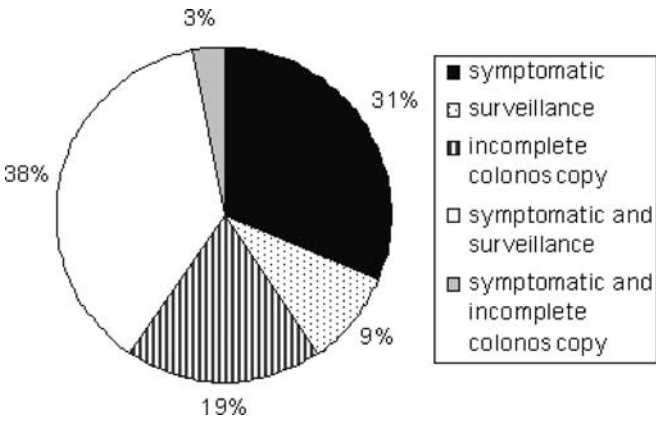

Fig. 2 Indications for CTC examinations for daily practice protocols in 33 institutions

Sensitivity analysis parameters dose modulation

We performed a sensitivity analysis to determine the influence of deviations in our data or assumptions in case of dose modulation on the outcomes of the study.

The above-mentioned correction of mAs values for patients of deviant weight are only approximate; it is known that this correction is different for different CT manufacturers, and even within one CT model the mA-weight curve can to a certain extent be adjusted [18, 19]. We checked the influence of the choice of the correction by

Table 3 Daily practice protocols in different institutions with median values of scan parameters and effective dose per protocol

	Number of simultaneously acquired slices				
	64	40	16	4	1
Number of protocols	21	1	11	4	2
Tube voltage (kV)	120	120	120	120	120
Rotation time (s)	0.5	0.4	0.5	0.5	0.75
Collimation (mm)	0.625	0.625	1.25	1.875	5
Effective mAs	58/50[a]	113	62/56[a]	83.5/30.5[a]	55
Dose modulation	12	1	2	-	-
Effective dose (mSv)	9.1	13.7	11.5	9.1	4.2

[a]Results for median values of collimation and effective mAs for supine and prone positions (supine/prone)

Table 4 Screening protocols in different institutions with median values of scan parameters and effective dose calculations per protocol

	Number of simultaneously acquired slices			
	64	16	4	1
Number of protocols	13	9	2	1
Tube voltage (kV)	120	120	120	120
Rotation time (s)	0.5	0.5	0.5	0.5
Collimation (mm)	0.6	1.125	1.125	5
Effective mAs	50/36[a]	40/32[a]	44	57
Dose modulation	7	5	-	-
Effective dose (mSv)	5.8	5.6	7.8	4.3

[a]Results for median value of effective mAs for supine and prone (supine/prone)

recalculating some of the data using 50% less or 50% more mAs correction for deviant weight than the correction shown in Fig. 1. We also checked the sensitivity of the outcomes on our assumption of a patient weight of 70 kg in case no unambiguous information was provided. If errors had been made, we assumed that the weight should have been somewhat larger, and therefore recalculations were made for weights of 75 and 80 kg.

Statistical analysis

For the effective dose and the various CT parameters, medians, minimum and maximum values were determined. The effective doses in the scanners with a different number of detector rows were compared by using the Kruskal-Wallis test. Differences between daily practice and screening protocols and between protocols of 16-, 40- and 64-detector row scanners with and without dose modulation were analyzed with the Wilcoxon-Mann-Whitney test. For comparison of results of the former study and the present study, we used the Wilcoxon signed ranks test. A p-value of less than 0.05 was considered to be significant.

Results

Response

With the search, 83 institutions were identified. After two reminder e-mails to non-responding institutions, we obtained a response from 50 institutions (60%), and from these institutions we received 37 (45%) questionnaires. Five authors answered that CT colonography was no longer performed, and eight authors responded positively, but finally did not return the questionnaire notwithstanding reminder e-mails. Three authors filled in the questionnaire with insufficient information for calculation of the effective dose, thus 34 institutions remained with complete questionnaires. Of these 34 institutions, 22 performed CTC for both daily practice and screening purposes, 11 only for daily practice and 1 institution only for screening. Indications for patients receiving CTC examinations in daily practice are indicated in Fig. 2.

Data on dose modulation

Seventeen institutions indicated that they used dose modulation for protocols for supine or prone scans, or both. Six of these institutions provided data for patients of 70 kg, and six institutions provided data for patients of another weight. Table 2 shows these weights, the uncorrected mAs values and the estimated mAs values for a patient of 70 kg using the relationship of Fig. 1. Five institutions did not provide unambiguous information on weight, and it was assumed that the weight of the patient was 70 kg.

CT parameters: daily practice and screening protocols

Overall, 37 CT machines were used by 34 institutions; 3 institutions use CT machines from 2 different manufacturers. In Table 3 a summary is given of the protocols for the daily practice patients. No significant differences in effective dose were found between scanners with different detector rows and between protocols with and without dose modulation. The median effective dose in 39 daily practice protocols was 9.1 mSv (range 2.8–22), 5.2 mSv (1.0–14.1) for supine and 3.0 mSv (0.6–9.8) for prone CT acquisition. The median effective dose per institution was also 9.1 mSv (2.8–22).

The median values for the 25 protocols for screening CT colonography in 22 institutions are given in Table 4. No significant difference in effective dose was found between scanners with different detector rows. The median effective dose for the screening protocols was 5.6 mSv (range 2.6–14.7), 2.8 mSv (1.0–6.1) for supine and 2.5 mSv (0.6–9.8) for prone CT acquisition. The median effective dose per institution was 5.7 mSv (2.6–12.2). See Fig. 3 for a histo-

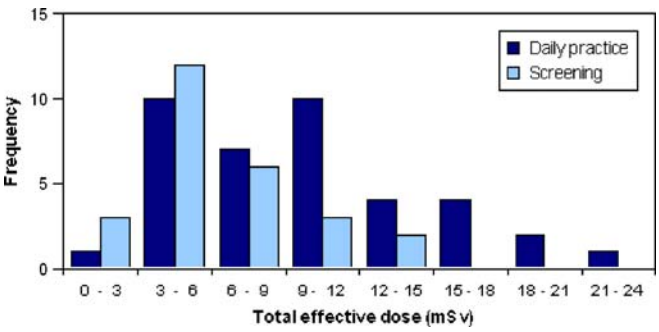

Fig. 3 Histogram of effective dose in daily practice and screening protocols

Table 5 Daily practice protocols

Institution	Scanner type	Slice number × collimation (mm)	Voltage (kV)	Rotatation time (s)	Pitch	Effective mAs	Effective dose supine (mSv)	Effective dose prone (mSv)	Total effective dose (mSv)
Amsterdam	Philips Brilliance 64	64×0.625	120	0.75	0.984	58	3.2	3.2	6.5
Bari	Toshiba Aquillon 16	16×1	120	0.5	0.875	29	3.0	3.0	6.1
Berlin	Toshiba Aquillon 64	64×0.5	120	0.5	0.9	48	5.1	5.1	10.1
Boston	Siemens Sensation 64	32×0.6	120	0.5	1	205/82[b]	12.5	5.0	17.4
Buenos Aires	Philips Brilliance 64	64×0.625	120	0.5	0.64	50	2.8	2.8	5.5
Candiolo[a]	GE Lightspeed 16	16×1.25	120	0.7	1.375	25	2.0	2.0	4.0
	GE Lightspeed 16	16×1.25	120	0.7	1.375	178/25[b]	14.1	2.0	16.1
Chandigarh[a]	GE Lightspeed plus	4×2.5	120	0.6	1.5	100/28[b]	8.0	2.2	10.2
	Siemens Sensation 16	16×1.5	120	0.5	1	200/60[b]	12.4	3.7	16.2
Chesterfield[a]	GE Lightspeed plus	4×2.5	120	0.5	1.5	67/33[b]	5.3	2.6	8.0
	GE Lightspeed Pro 16	16×1.25	120	0.6	1.375	87/65[b]	7.1	5.3	12.3
Chicago	Philips Brilliance 64	64×0.625	120	0.5	1	50	2.8	2.8	5.6
Como	GE VCT	64×0.625	120	0.5	0.984	53	5.2	5.2	10.4
Copenhagen	GE CT/i	1×5	120	1	1.3	54	2.0	2.0	4.1
Dusseldorf	Siemens Sensation 64	32×0.6	120/100[b]	0.5	1.2	120/20[b]	7.4	0.7	8.1
Jerusalem[a]	Philips MxIDT	16×1.5	120	0.5	1	50/100[b]	3.0	6.1	9.1
	GE VCT	64×0.625	120	0.5	1	50/100[b]	4.9	9.8	14.7
Latina	GE VCT	64×0.625	120	0.5	1.375	116/73[b]	11.7	7.4	19.0
Lausanne	GE VCT	64×0.625	120	0.6	1.375	131/87[b]	13.2	8.8	22.0
Leuven	Siemens Sensation 16	16×0.75	120/140[b]	0.5	0.9	170/12[b]	10.6	1.2	11.9
London	Siemens Sensation 64	32×0.6	120	0.5	0.95	123/120[b]	7.4	7.2	14.5
Muenster	Siemens Definition	32×0.6	120	0.5	1.2	157/10[b]	9.0	0.6	9.7
Munich	Siemens Sensation 64 Toshiba Aquilion	32×0.6	120	0.5	1.25/1.4[b]	80/30[b]	4.9	1.8	6.7
Naples	Multi/4	4×1	120	0.5	1.375	109/51[b]	13.0	6.1	19.1
New York (1)	GE Lightspeed 16	16×1.25	120	0.5	1.375	56	4.4	4.4	8.9
New York (2)	GE CT/i	1×5	120	0.5	1.5–2.0	57	2.1	2.1	4.3
New York (3)	Siemens Sensation	32×0.6/24×1.2[b]	120	0.5	1	34	2.1	2.0	4.0
Nonsan	Philips MxIDT	16×1.5	120	0.5	0.8–1.0	191/92[b]	11.5	5.6	17.1
Padova	GE Lightspeed 16	16×1.25	120	0.8	1.5	27	2.1	2.1	4.3
Paris	Philips Brilliance 64	64×0.625	120	0.5	1.11	100	5.6	5.6	11.2
Perth[a]	Philips Brilliance 64	64×0.625	120	0.4	1.094	40	2.2	2.2	4.5
	Philips Brilliance 64	64×0.625	120	0.75/0.4[b]	0.891/1.094[b]	174/40[b]	9.7	2.2	11.9
Pisa	GE Light Speed Plus	4×1.25	120	0.5	1.5	17	1.7	1.7	3.3
Rochester[a]	GE LightSpeed 16	16×0.625	120	0.5	1.375	62	5.7	5.7	11.5
	Siemens Sensation 64	32×0.6	120	0.5	1.4	43	2.6	2.6	5.3
Roeselare	Siemens Sensation 64	32×0.6	140/120[b]	0.5	1.4	10/30[b]	1.0	1.9	2.8
Rome	Siemens Sensation 64	32×0.6	120	0.5	1	100/50[b]	6.1	3.0	9.1
San Francisco	GE VCT	64×0.625	120	0.5	0.984	38	3.7	3.7	7.5
Ulm	Philips Brilliance 40	40×0.625	120	0.4	0.6	113	6.9	6.9	13.7
					Median per protocol		5.2	3.0	9.1

[a]Institutions that use two scan protocols
[b]Protocol with different settings for supine and prone (supine/prone). The total effective dose is the sum of the supine and prone dose; for these calculations the not rounded off numbers are used

gram of the effective doses of daily practice and screening protocols.

Overviews of CT parameters and effective dose for daily practice protocols and screening protocols per institution are given in Tables 5 and 6. The effective doses for the screening protocols were significantly lower than for the daily practice protocols (p=0.007).

Sensitivity analysis parameters dose modulation

Recalculations using 50% less or 50% more mAs correction than the nominal correction for the six institutions that provided data for deviant weight (Table 2) produced the following results: Effective doses per institution remained the same except for screening protocols in which the

Table 6 Screening protocols

City	Scanner type	Slice number × collimation	Voltage (kV)	Rotatation time (s)	Pitch	Effective mAs	Effective dose supine (mSv)	Effective dose prone (mSv)	Total effective dose (mSv)
Bari	Toshiba Aquillon 16	16×1	120	0.5	0.875	29	3.0	3.0	6.1
Boston	Siemens	32×0.6	120	0.5	0.75	82	4.8	4.8	9.7
Buenos Aires	Philips Brilliance 64	64×0.6	120	0.5	0.64	38	2.1	2.1	4.2
Candiolo	GE Lightspeed 16	16×1.25	120	0.7	1.375	25	2.0	2.0	4.0
Chicago	Philips Brilliance 64	64×0.625	120	0.5	1	50	2.8	2.8	5.6
Dusseldorf	Siemens Sensation 64	32×0.6	100	0.5	1.2	50/30[b]	1.6	1.0	2.6
Jerusalem[a]	Philips MxIDT	16×1.5	120	0.5	1	100/50[b]	3.0	6.1	9.1
	GE VCT	64×0.625	120	0.5	1	100/50[b]	4.9	9.8	14.7
Latina	GE VCT	64×0.625	120	0.5	1.375	36	3.6	3.6	7.3
Leuven	Siemens Sensation 16	16×0.75	120/140[b]	0.75	0.9	40/12	2.5	1.2	3.8
Madison[a]	GE Lightspeed 16	16×1.25	120	0.5	1.375	32	2.5	2.5	5.1
	GE Lightspeed Pro16	16×1.25	120	0.5	1.375	31	2.5	2.5	5.0
Muenster	Siemens Definition	32×0.6	120	0.5	1.2	90/10[2]	5.2	0.6	5.8
Munich	Siemens Sensation 64	32×0.6	120	0.5	1.25/1.40[b]	80/30[b]	4.9	1.8	6.7
Naples	Toshiba Aquilion Multi/4	4×1	120	0.5	1.375	51	6.1	6.1	12.2
New York (1)	GE Lightspeed 16	16×1.25	120	0.5	1.375	56	4.4	4.4	8.9
New York (2)	GE CT/i	1×5	120	0.5	1.75	57	2.1	2.1	4.3
New York (3)	Siemens Sensation 64	32×0.6/24×1.2[b]	120	0.5	1	34	2.1	2.0	4.0
Pisa	GE Light Speed Plus	4×1.25	120	0.5	1.5	37	1.7	1.7	3.3
Rochester[a]	GE LightSpeed 16	16×0.625	120	0.5	1.375	62	5.7	5.7	11.5
	Siemens Sensation 64	32×0.6	120	0.5	1.4	43	2.6	2.6	5.3
Roeselare	Siemens Sensation 64	32×0.6	120	0.5	1.4	10/30[b]	1.0	1.9	2.8
Rome	Siemens Sensation 64	32×0.6	120	0.5	1	100/10[b]	6.1	0.6	6.7
San Francisco	GE VCT	64×0.625	120	0.5	0.984	38	3.7	3.7	7.5
Ulm	Philips Mx 8000	16×0.75	120	0.75	1	42	2.8	2.8	5.6
					Median per protocol		2.8	2.5	5.6

median dose for 50% less correction increased from 5.7 to 5.9 mSv. Recalculations for the five institutions that did not provide unambiguous information on weight resulted in a reduction of the median effective dose for daily practice from 9.1 to 8.9 mSv (for 75 kg) and to 8.2 mSv (80 kg) and for screening from 5.7 to 5.6 mSv and to 5.4 mSv for 75 and 80 kg, respectively.

Overranging planned trajectory of the volume examined

The increase in dose due to overranging of the planned trajectory of the volume examined was calculated for each CT protocol. For 64- and 40-detector-row CT systems the increase in dose was on the average 14%, for 16-detector-row CT systems 10% and for 4-detector-row and single-detector-row CT systems 4%.

Comparison with CTC performed in 2004

We compared effective doses of the 17 institutions that also responded to our questionnaire in the first study. In this study only the effective doses for daily practice were determined. In these institutions the median effective dose for daily practice was at that time 11.0 mSv (range 4.2–21.0). In these figures the effect of overranging has been taken into account [12]. The current median dose in these institutions is 9.7 mSv. This difference is not significant. In the present study, 17 institutions used dose modulation (50%) together with automatic current selection, while in 2004 no institution used this for CTC. Finally we compared the number of detector rows of the CT systems used in the earlier study and now. In 2004, 82% (23/28) of the institutions used a CT system with fewer than 16 detector rows and 18% (5/28) used a 16-detector-row CT system. In 2007 only 18% (6/34) used a CT system with fewer than 16 detector rows and 62% (21/34) used a 64-detector-row CT system.

Discussion

In this dose evaluation study, we give an overview of the current protocols and estimates of the effective dose for CTC. A questionnaire was used to obtain information on the scanner types and CT parameters that are used at present for CTC. The effective doses were lower for the screening protocols than for the daily practice protocols, with median values of respectively 5.7 and 9.1 mSv ($p < 0.05$). No differences in effective doses were found for the different detector row CT systems. The median effective dose of CTC for the institutions that also were included in the dose evaluation study of 2004 was slightly lower than in 2007 (9.7 and 11.0 mSv, respectively), but this difference was not significant.

It is not unexpected that the effective doses for screening protocols are lower than for daily practice protocols. When CTC is used as a screening procedure for patients at average risk for colorectal cancer, the radiation dose must be minimized to maintain the appropriate benefit-risk ratio [20, 21]. An earlier study has shown good diagnostic accuracy with low tube current protocols. Even for effective doses considerably less than 1 mSv per CTC examination (supine and prone), only a minimal, not significant decrease in sensitivity for polyps of ≥6 mm compared to a dose level of 10 mSv was found [10]. Other studies have also shown that CT studies with a lower dose can give sufficient image quality for polyp detection [8, 22, 23]. In this study a median dose for screening protocols of 5.6 mSv was found, with a range of 2.6 to 14.7 mSv. Obviously there is still ample opportunity for dose reduction in screening CTC.

The number of CT systems with 16 or more detector rows now used for CT colonography has increased considerably in comparison with the previous questionnaire (2004). In this study the effective dose for the 64-detector-row CT systems did not significantly differ from that found for 16- and 4-detector-row CT systems: for the daily practice protocols the dose was 9.1 mSv for 64-detector-row CT systems and 11.7 and 9.1 mSv for 16- and 4-detector row machines, respectively.

All new CT systems can be operated with dose modulation with the possibility of dose reduction without loss of image quality [24]. Half of the institutes now use dose modulation in their CTC protocols. Until now this appears not to have resulted in a reduction in effective dose.

In comparison with the effective doses in 2004 of the former study, the effective doses for daily practice protocols showed a small, not significant reduction from 11.0 mSv in 2004 to 9.7 mSv at present. The effective doses for these protocols have thus remained virtually the same during the last few years. This may have different reasons. A number of institutions may value a higher image quality more than a lower dose. This hypothesis is supported by the large range of effective doses found in the present study: from less than 3 mSv to more than 20 mSv. Some of these differences may be explained by differences in the CT examination, for example, the use of intravenous contrast medium (which is mostly used for high-risk patients that require higher image quality) necessitates a higher dose [25].

This study has some limitations. Only 50 (60%) of the 83 institutions that were found with our search responded. Of the responding institutions 37 returned the questionnaire and 5 answered they had stopped performing CTC (in total 51% of all sent e-mails). A reason for not returning the questionnaire might be difficulties with obtaining the CT parameters, especially for the institutions that use a CT protocol with dose modulation.

The accuracy of data obtained with any questionnaire is never completely reliable, and that is especially the case in

the present situation for the protocols with dose modulation. Of course more accurate results would have been obtained if we had examined a humanoid phantom in all institutions with their CTC protocol(s), but this was practically not feasible. A first uncertainty is that we made the approximation to use the average mAs value (instead of the actual, varying mA value) in the estimation of the effective dose. This appears to be a reasonable approximation, however [16]. Secondly, some institutions provided both effective mAs values and CTDI values and/or DLP values. In case discrepancies were present between these values, the effective mAs values were used in the dose calculations. Only for two institutions larger (>25%) discrepancies were present, however.

We also performed an analysis to determine how sensitive the outcomes of the study are for any deviations in the data or assumptions in case of dose modulation. It appeared that the influence of the exact relation between weight and mAs value (Fig. 1) was limited. Also the exact choice of the weight for 5 of the 17 institutions that used dose modulation and did not provide unambiguous information on the weight of the patient influenced the results only to a limited degree.

Conclusion

The median effective dose for CTC colonography at present is significantly lower for screening protocols (5.6 mSv) than for daily practice protocols (9.1 mSv), which is important because of differences in benefit-risk ratios for patients in screening and in daily practice. We found that the use of CT systems with a different number of detector rows does not influence the effective dose. Furthermore, the current effective dose has not significantly changed compared to the dose in 2004, but the number of CTC protocols with dose modulation increased substantially.

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